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# Age-Specific Prevalence of Visual Impairment and Refractive Error in Children Aged 3–10 Years in Shanghai, China

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**PURPOSE.** We assessed changes in age-specific prevalence of refractive error at the time of starting school, by comparing preschool and school age cohorts in Shanghai, China.

**METHODS.** A cross-sectional study was done in Jiading District, Shanghai during November and December 2013. We randomly selected 7 kindergartens and 7 primary schools, with probability proportionate to size. Chinese children ( $n = 8398$ ) aged 3 to 10 years were enumerated, and 8267 (98.4%) were included. Children underwent distance visual acuity assessment and refraction measurement by cycloplegic autorefractometry and subjective refraction.

**RESULTS.** The prevalence of uncorrected visual acuity (UCVA), presenting visual acuity, and best-corrected visual acuity in the better eye of  $\leq 20/40$  was 19.8%, 15.5%, and 1.7%, respectively. Among those with UCVA  $\leq 20/40$ , 93.2% could achieve visual acuity of  $\geq 20/32$  with refraction. Only 28.7% ( $n = 465$ ) of children with UCVA in the better eye of  $\leq 20/40$  wore glasses. Prevalence of myopia (spherical equivalent  $\leq -0.5$  diopters [D] in at least one eye) increased from 1.78% in 3-year-olds to 52.2% in 10-year-olds, while prevalence of hyperopia (spherical equivalent  $\geq +2.0$  D) decreased from 17.8% among 3-year-olds to 2.6% by 10 years of age. After adjusting for age, attending elite “high-level” school was statistically associated with greater myopia prevalence.

**CONCLUSIONS.** The prevalence of myopia was lower or comparable to that reported in other populations from age 3 to 5 years, but increased dramatically after 6 years, consistent with a strong environmental role of schooling on myopia development.

**Keywords:** visual impairment, refractive error, myopia

Uncorrected refractive error is the most common cause of visual impairment (VI) in children.<sup>1–3</sup> According to the World Health Organization (WHO), approximately 19 million children and adolescents 5 to 15 years of age suffer from VI, among which, approximately 12.8 million cases (67%) are due to uncorrected refractive error.<sup>2</sup> Nearly half of these children

reside in China, with myopia accounting for the vast majority.<sup>4</sup> The prevalence of myopia exceeds 60% among 12-year-olds in China after primary school, reaches nearly 80% at 16 years of age after junior high school, and surpasses 90% in university students.<sup>5–7</sup> High prevalence of myopia also has been observed in other parts of East Asia, such as Singapore, South Korea,



Japan, Hong Kong, and Taiwan.<sup>8-12</sup> In recent decades, increases in myopia prevalence have been reported in areas previously only mildly or moderately affected, such as Australia, Israel, the United States, Finland, and other European countries, although the recent prevalence of myopia in those areas still is much less than that in East Asia.<sup>13-17</sup> Myopia not only is among the leading causes of VI and blindness, but if it progresses to high or pathologic myopia,<sup>18</sup> it can lead to retinal detachment, cataract, glaucoma, and myopic retinopathy.<sup>19</sup>

The Refractive Error Study in Children (RESC) reported that the prevalence of myopia was higher in China, compared to Nepal, Chile, India, South Africa, and Malaysia,<sup>20</sup> consistent with other reports of high myopia rates among children of east Asian origin.<sup>8-12,21</sup> Given the rapid urbanization occurring in China, characterized by a more rigorous education system and a growing popularity of electronic devices, such as mobile phones and tablet computers, children are increasingly likely to take part in near work activities. The prevalence of myopia and other types of refractive errors may have changed over the past decade since RESC was performed. In addition, very few population studies have addressed refractive error prevalence in preschool children in China.<sup>22-24</sup>

To date, to our knowledge, there have been no studies concerning VI and refractive error prevalence in the pediatric population in Shanghai, a major center of economic activity in China. Few cross-sectional refractive error studies anywhere have included preschool and school-aged children, allowing for an assessment of the impact of school exposure on myopia prevalence. The Shanghai Children Eye Study (SCES) examined children aged 3 to 10 years old in Jiading district, Shanghai, and collected data on the prevalence of VI and refractive error, including myopia, hyperopia, astigmatism, and anisometropia. This study also explored causes of VI and potential risk factors for myopia in the study population. In addition, results from preschool children in the current study also may be compared to limited existing data on preschool children of Chinese and other ethnicities.<sup>22-26</sup>

## METHODS

Ethics approval was obtained from the Ethics Committee of the Shanghai General Hospital, Shanghai Jiaotong University, and the study procedures adhered to the Declaration of Helsinki for research involving human subjects. A parent or legal guardian provided written informed consent for all children. If a child was 6 years or older, their oral assent also was obtained, and if they were 10 years or older, they also provided written assent.

## Study Population

All 58 kindergartens and 34 primary schools in Jiading district were divided into two levels (general level and high level) according to the standard classification of the Jiading Education Bureau. By probability proportion to size method, 2850 children from 7 kindergartens, including 4 general and 3 high level kindergartens, and 5548 children from 7 primary schools, including 4 general and 3 high level primary schools, were randomly chosen to participate in the study, representing approximately 17,000 children of kindergarten age and 33,097 children in primary grades 1 to 5, according to statistics from the Jiading Education Bureau. Schools that were specially designed for migrant children were not included in the sample, though substantial numbers of migrant children did participate. Generally, children in the high level schools (or kindergartens) have more experienced teachers and better-equipped facilities than children in general level schools.

According to previous reported myopia prevalence rates in urban China,<sup>23,27</sup> a sample size of 2409 preschool children and 5292 primary school children were required to attain 95% confidence intervals with a precision of 0.01 and 0.02, respectively, accounting for a cluster design effect of 1.8 and an estimated response rate of 70%. Children aged 3 to 10 years were included in the study, which corresponded to the junior to senior classes of kindergarten, and primary school grades 1 to 5.

Jiading district is located in the Northwest suburban area of Shanghai, with an area of 463 square kilometers and a population of 567,139 at the end of 2012. The school attendance rate for kindergarten was 98.8%, and for primary schools 100% in Jiading in 2012.<sup>28</sup> According to Shanghai Statistical Year Book, in 2012, the average income of urban and rural residents in Shanghai was 40,188 Chinese Yuan (CNY) and 17,401 CNY, respectively. The average income of urban and rural residents in Jiading was 33,222 CNY and 19,429 CNY, respectively, similar to Shanghai overall.<sup>29</sup>

## Visual Acuity Testing

Two ophthalmic assistants performed distance visual acuity testing with tumbling E Early Treatment Diabetic Retinopathy Study (ETDRS) charts (LCD backlit lamp, WH0701; Guangzhou Xieyi Weishikang, Guangzhou, China), at a distance of 4 m, as has been described previously in the ETDRS protocol.<sup>20</sup> Before testing, the procedure for the test was explained to children. For children younger than 6 years, their teachers were responsible for helping to explain procedures before testing. Children were requested in advance to bring their glasses to the ocular examination site. Children initially underwent assessment of presenting visual acuity (PVA), with correction if worn, then uncorrected visual acuity (UCVA). The height of the top line (20/20) on the vision chart was adjusted to match the ocular position of the child, and children were directed to avoid squinting or head tilting. For children having spectacles, the power was measured with a lensometer. The right eye was tested first and then the left, each time with occlusion of the fellow eye.

## Ocular Examinations

A trained team consisting of an ophthalmologist, 3 to 5 optometrists, 3 to 5 ophthalmic assistants and a study coordinator conducted ocular examinations between November and December 2013. After assessment of visual acuity as above, axial length was measured by an IOL Master (version 5.02; Carl Zeiss, Jena, Germany), and a slit lamp (YZ5X; 66 Vision Tech, Suzhou, China) examination and direct ophthalmoscopy were performed by an ophthalmologist. Intraocular pressure was measured by an optometrist using noncontact tonometry (NT-1000; Nidek, Tokyo, Japan), and children having a peripheral anterior chamber depth of  $>1/2$  the thickness of cornea, IOP  $\leq 25$  mm Hg, and parental consent for cycloplegia received one drop of 0.5% proparacaine hydrochloride in each eye followed by two drops of cyclopentolate 1.0% (Cyclogyl; Alcon, Fort Worth, TX, USA) 5 minutes apart. If the pupil size was  $\geq 6$  mm and the light reflex was absent after 30 minutes, cycloplegia was deemed adequate. Otherwise, an additional drop of proparacaine and cyclopentolate was given, and failure of cycloplegia was recorded if the above standard had not been reached after 15 additional minutes. Subsequently, autorefractometry (KR-8900; Topcon, Tokyo, Japan) and subjective refraction were performed by an experienced optometrist. Subjective refraction and best corrected visual acuity (BCVA) were determined in children with UCVA  $\leq 20/40$  in either eye, with the power identified by autorefractometry as

**TABLE 1.** Number of Children Enumerated, Examined, Agreeing to, and Completing Cycloplegia

| Variable     | Enumerated Number (%) | Examined Number (% Among Enumerated) | Consented for Cycloplegia Number (% Among Enumerated) | Completed Cycloplegic Refraction Number (% Among Enumerated) |
|--------------|-----------------------|--------------------------------------|---|--|
| Age, y       |                       |                                      |   |  |
| 3 (36–47 mo) | 599 (7.1)             | 524 (87.5)                           | 293 (48.9)  | 281 (46.9)   |
| 4 (48–59 mo) | 1222 (14.6)           | 1201 (98.3)                          | 834 (68.3)  | 817 (66.9)   |
| 5 (60–71 mo) | 981 (11.7)            | 977 (99.6)                           | 702 (71.6)  | 691 (70.4)   |
| 6            | 1235 (14.7)           | 1230 (99.6)                          | 872 (70.6)  | 862 (69.8)   |
| 7            | 1229 (14.6)           | 1220 (99.3)                          | 868 (70.6)  | 853 (69.4)   |
| 8            | 1218 (14.5)           | 1209 (99.3)                          | 771 (63.3)  | 759 (62.3)   |
| 9            | 1145 (13.6)           | 1139 (99.5)                          | 753 (65.8)  | 744 (65.0)   |
| 10           | 967 (11.5)            | 962 (99.5)                           | 702 (72.6)  | 692 (71.6)   |
| Sex          |                       |                                      |   |  |
| Male         | 4535 (54.0)           | 4453 (98.2)                          | 3069 (67.7)   | 3024 (66.7)  |
| Female       | 3863 (46.0)           | 3814 (98.7)                          | 2549 (66.0)   | 2508 (64.9)  |
| Total        | 8398 (100.0)          | 8267 (98.4)                          | 5618 (66.9)   | 5532 (65.9)  |

the starting point. Children failing vision screening as above who lacked consent for cycloplegia also underwent autorefraction followed by subjective refraction by an optometrist. Three consecutive autorefraction and corneal curvature readings were obtained and the average computed automatically in each eye. If any two measurements varied by  $>0.5$  diopters (D), additional measurements were required until three measurements fell within 0.5 D.

### Quality Control Procedures

Before initiating the study, all members of the examination group were trained in the standard protocol, and were tested on their performance of the procedures for which they were responsible. In the field, the coordinator reviewed all forms, and directed children to fill in any incomplete items. The autorefractor was calibrated daily using a model eye. Data were entered using Epidata 3.1 software (The Epidata Association, Odense, Denmark) by two trained data entry personnel, who were checked against each other, with adjudication performed in the event of discrepancy. A second check was made on 5% of forms for consistency with the database.

### Statistical Analyses

We used SAS 9.2 (SAS Institute, Cary, NC, USA) for cleaning, performing logical checks on, and merging the data. Prevalence rates of VI based on UCVA, PVA and BCVA were calculated. Definitions for refractive error were in accordance with the multicountry RESC.<sup>20</sup> Myopia was defined as spherical equivalent (SE) refraction  $\leq -0.5$  D,  $-0.75$ ,  $-1.0$ , and  $-6.0$  D, and mild hyperopia and hyperopia as SE refraction  $\geq +0.5$  and  $\geq +2.0$  D, respectively. Children were considered myopic if at least one eye was myopic, and hyperopic if at least one eye was hyperopic but neither was myopic, and emmetropic if neither eye was myopic or hyperopic. Children with myopia were further subdivided into low ( $>-3.0$  and  $\leq -0.5$  D) moderate ( $>-6.0$  and  $\leq -3.0$  D) and high ( $\leq -6.0$  D) myopia. Children were considered to have astigmatism if cylindrical power was  $\geq 1.0$  D in either eye, and anisometropic if the SE refractive power differed between the two eyes by  $\geq 1.0$  D. Amblyopia was defined using the identical criteria described in the RESC.<sup>20</sup>

To explore the associations of age, sex, school type (high versus general level), and migration (Native versus Migrant)

with myopia prevalence, an logistic analysis was performed with stepwise mode. The  $\chi^2$  test was used to assess differences between categorical variables. Confidence intervals around prevalence figures were calculated using two methods: based on a normal distribution accounting for cluster design effects and based on an exact binomial distribution without adjusting for design effects.<sup>20</sup> Data analyses were conducted using SAS 9.2 (SAS Institute) and SPSS 22.0 (IBM SPSS, Inc., Chicago, IL, USA). A *P* value less than 0.05 was considered to be statistically significant.

## RESULTS

### Study Population

A total of 2850 kindergarten children and 5548 primary school children were enumerated. Among them, 2752 (96.6%) and 5515 (99.4%) children participated in examinations at kindergartens and primary schools, respectively (Table 1). The number of boys (54.0% and 53.9%, respectively, of the kindergarten and primary samples) participating was larger than for girls, which is consistent with the proportion of males under 17 in Jiading District (55.2%).<sup>28</sup> There were 3635 migrant children in the present study, accounting for 44% of all participants. The proportion was similar to the percentage of migrant children in Shanghai as a whole according to the sixth national census (46.2% in 2010).<sup>30</sup>

Written informed consent for cycloplegia was received in 1837 (64.5%) of enumerated kindergarten and 3781 (68.2%) of primary school children. Excluding those who were not suitable for, uncooperative with, or failed cycloplegia or autorefraction, a total of 1806 (63.4%) kindergarten children and 3726 (67.2%) primary school children successfully completed cycloplegic autorefraction. Age (with cycloplegia  $6.82 \pm 2.07$ , without cycloplegia  $6.66 \pm 2.16$ ,  $P < 0.001$ ), sex (with cycloplegia 54.7% boys, without cycloplegia 52.2% boys,  $P = 0.038$ ), and type of school (with cycloplegia 58.1% general, without cycloplegia 41.1% general,  $P < 0.001$ ) differed statistically significantly by cycloplegia status. However, visual acuity and axial length did not differ significantly by cycloplegia status (data not shown). Therefore, the unbalance in children with and without successful cycloplegia appears not to have influenced refractive status among the two groups.



**TABLE 2.** Distribution of UCVA, PVA, and BCVA (Percentage and 95% CI) and Percentage Wearing Glasses

| VA Category                              | According to UCVA* |           | No. Wearing Glasses<br>(% Among Those<br>With Corresponding<br>UCVA Category) | According to PVA |           | According to BCVA |           |
|--|--------------------|-----------|---|------------------|-----------|-------------------|-----------|
|  | No. (%)            | 95% CI    |   | No. (%)          | 95% CI    | No. (%)           | 95% CI    |
| Both eyes $\geq 20/32$                   | 5679 (69.3)        | 64.7–73.9 | 35 (0.6)  | 5979 (73.0)      | 68.2–77.7 | 7973 (97.3)       | 96.5–98.1 |
| One eye $\geq 20/32$                     | 895 (10.9)         | 9.9–12.0  | 55 (6.2)  | 944 (11.5)       | 10.5–12.6 | 84 (1.0)          | 0.7–1.3   |
| $\geq 20/63$ to $\leq 20/40$ better eye  | 1231 (15.0)        | 11.3–18.7 | 204 (16.6)  | 1132 (13.8)      | 10.1–17.6 | 134 (1.6)         | 1.0–2.3   |
| $\geq 20/160$ to $\leq 20/80$ better eye | 348 (4.3)          | 3.3–5.2   | 223 (64.1)  | 135 (1.7)        | 1.2–2.1   | 5 (0.1)           | 0.0–0.1   |
| $\leq 20/200$ better eye                 | 43 (0.5)           | 0.2–0.8   | 38 (88.4)   | 6 (0.1)          | 0.0–0.2†  | 0 (0)             | 0         |
| Total                                    | 8196 (100)         |           | 555 (6.8)   | 8196 (100)       |           | 8196 (100)        |           |

\* 8196 children with complete records of UCVA, PVA, and BCVA. Measurement for UCVA, PVA, or BCVA was not possible in 71 children.

† Exact binomial distribution without considering cluster design effect was used to calculate 95% CIs.

## VI and Glasses Wear

The prevalence of UCVA, PVA, and BCVA in the better eye of  $\leq 20/40$  was 19.8%, 15.5%, and 1.7%, respectively (Table 2). The proportion of children wearing glasses on the day of examination increased with worsening UCVA. Only 28.7% ( $n = 465$ ) of children with UCVA in the better eye  $\leq 20/40$  wore glasses (Table 2). This proportion was 26.0% for girls and 31.3% for boys ( $\chi^2$  test,  $P = 0.017$ ).

Visual impairment was overwhelmingly caused by refractive error. Among 2517 children with UCVA  $\leq 20/40$  in one or both eyes, 2346 (93.2%) attained acuity  $\geq 20/32$  in one or both eyes with refractive correction. Amblyopia was the cause of VI uncorrectable to  $\geq 20/32$  in 76 (0.93%) children in one or both eyes. Other causes of vision loss were uncommon: one (0.01%) child was impaired due to blepharoptosis of the upper lid in one eye.

The prevalence of UCVA, PVA, and BCVA in the better eye  $\leq 20/50$  differed significantly by age ( $\chi^2$  test,  $P < 0.001$ ,  $P < 0.001$ ,  $P = 0.007$ , respectively), but not by sex ( $P = 0.621$ , 0.287, 0.948 respectively; Table 3). The prevalence of UCVA and PVA  $\leq 20/50$  decreased from 3 to 6 years old, and then increased until the age of 10 years. The prevalence of UCVA  $\leq 20/50$  was significantly higher among native than migrant children ( $P < 0.001$ ); however, values for PVA and BCVA did not differ significantly between the two groups ( $P = 0.942$ , 0.322, respectively).

## Refractive Error

Cycloplegic autorefraction was completed in both eyes for 5532 (65.9%) children (Fig. 1). Mean SE refraction of boys and girls decreased from 1.20 D and 1.32 D, respectively, among 3-year-olds, to  $-0.81$  D and  $-0.82$  D, respectively among 10-year-olds. Girls were less myopic before age 8 years, and became as or more myopic than boys subsequently (Fig. 1).

Prevalence of myopia ( $SE \leq -0.5D$ ) increased from 1.8% in children aged 3 years to 52.2% by age 10, while prevalence of hyperopia decreased from 17.8% among 3-year-olds to 2.6% by 10 years of age (Table 4). Among 1114 myopic children, 910 (81.7%) had low myopia ( $> -3.0$  and  $\leq -0.5$  D), 187 (16.8%) moderate ( $> -6.0$  and  $\leq -3.0$  D), and 17 (1.5%) high ( $\leq -6.0$  D) myopia. Prevalence of high myopia was 0.33%. The number of children wearing glasses was 143 (15.7%), 131 (70.1%), and 15 (88.2%) among children with low, moderate, and high myopia.

Older age (odds ratio [OR] = 2.00; 95% confidence interval [CI], 1.91–2.10;  $P < 0.001$ ), attendance at high-level schools (OR = 1.42, 95% CI, 1.20–1.68;  $P < 0.001$ ), and being a native child (OR = 1.28, 95% CI, 1.08–1.52;  $P = 0.004$ ) were all associated with a higher risk of myopia in multivariable logistic analyses. Sex was unassociated with risk of myopia ( $P = 0.813$ ). Additional analyses stratifying by age before and after 6 (data not shown) showed that the significantly greater myopia prevalence among children attending high-level schools only

**TABLE 3.** Prevalence of VI According to UCVA, PVA, and BCVA  $\leq 20/50$  (or  $\leq 20/40$ ) in Better Eye by Age and Sex

| Variable | No.  | UCVA            |                 | PVA             |                 | BCVA            |                 |
|----------|------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|          |      | ≤20/50, No. (%) | ≤20/40, No. (%) | ≤20/50, No. (%) | ≤20/40, No. (%) | ≤20/50, No. (%) | ≤20/40, No. (%) |
| Age, y   |      |                 |                 |                 |                 |                 |                 |
| 3        | 477  | 39 (8.2)        | 128 (26.8)      | 38 (8.0)        | 127 (26.6)      | 5 (1.1)         | 78 (16.4)       |
| 4        | 990  | 61 (6.2)        | 238 (24.0)      | 58 (5.9)        | 234 (23.6)      | 5 (0.5)         | 35 (3.5)        |
| 5        | 974  | 50 (5.1)        | 158 (16.2)      | 42 (4.3)        | 150 (15.4)      | 3 (0.3)         | 9 (0.9)         |
| 6        | 1230 | 38 (3.1)        | 113 (9.2)       | 28 (2.3)        | 97 (7.9)        | 2 (0.2)         | 5 (0.4)         |
| 7        | 1218 | 66 (5.4)        | 112 (9.2)       | 43 (3.5)        | 87 (7.1)        | 0 (0.0)         | 2 (0.2)         |
| 8        | 1208 | 159 (13.2)      | 224 (18.5)      | 97 (8.0)        | 163 (13.5)      | 2 (0.2)         | 4 (0.3)         |
| 9        | 1137 | 228 (20.1)      | 306 (26.9)      | 121 (10.6)      | 208 (18.3)      | 1 (0.1)         | 1 (0.1)         |
| 10       | 962  | 267 (27.8)      | 343 (35.7)      | 117 (12.2)      | 207 (21.5)      | 4 (0.4)         | 5 (0.5)         |
| Sex      |      |                 |                 |                 |                 |                 |                 |
| Male     | 4414 | 482 (10.9)      | 817 (18.5)      | 281 (6.4)       | 623 (14.1)      | 12 (0.3)        | 69 (1.6)        |
| Female   | 3782 | 426 (11.3)      | 805 (21.3)      | 263 (7.0)       | 650 (17.2)      | 10 (0.3)        | 70 (1.9)        |
| Native   |      |                 |                 |                 |                 |                 |                 |
| Native   | 4583 | 572 (12.5)      | 1066 (23.3)     | 305 (6.7)       | 813 (17.7)      | 10 (0.2)        | 88 (1.9)        |
| Migrant  | 3613 | 336 (9.3)       | 556 (15.4)      | 239 (6.6)       | 460 (12.7)      | 12 (0.3)        | 51 (1.4)        |
| Total    | 8196 | 908 (11.1)      | 1622 (19.8)     | 544 (6.6)       | 1273 (15.5)     | 22 (0.3)        | 139 (1.7)       |

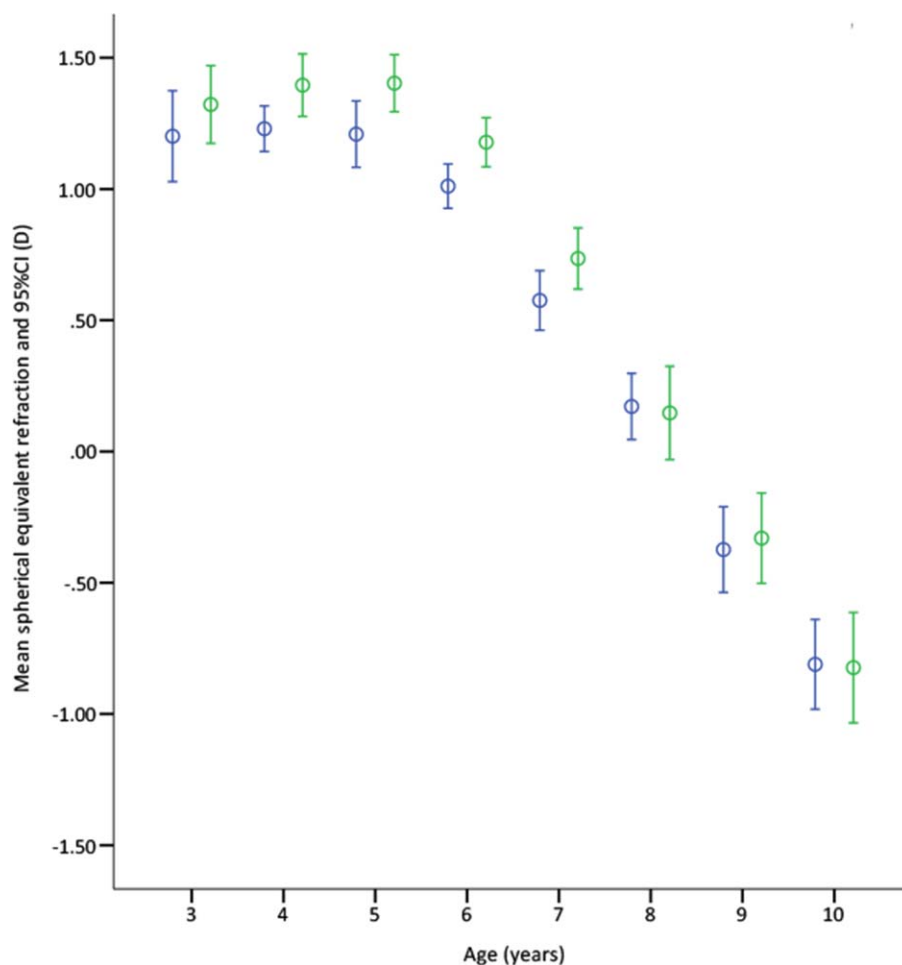


FIGURE 1. Mean SE refraction and 95% CI according to age and sex in the right eye. Blue stands for boys and green stands for girls.

became apparent among older children, and was not present before age 6.

## DISCUSSION

Prevalence of myopia among 10-year-olds (52.2%) was very high in the present population, much higher than in India, Malaysia, Chile, and other countries enrolled in the RESC.<sup>31-33</sup> The prevalence also was higher than the age-specific prevalence of 10-year-olds reported in Guangzhou (30.1%),<sup>34</sup> Beijing (33.6%),<sup>35</sup> Shandong (38.9%),<sup>6</sup> and Yongchuan (9.4%)<sup>36</sup> in mainland China, but lower than observed in Singapore (53.1% among 9-year-olds)<sup>37</sup> and Hong Kong (59.3% in 10-year-olds).<sup>11</sup>

Logistic analyses indicated that older age, being a native child, and attendance at high-level schools were associated with greater myopia risk. As elsewhere in China, children in Shanghai attending high-level schools will experience greater homework demands and pressure from teachers, parents, and peers to study. Their higher myopia prevalence is consistent with recent literature regarding educational exposure as an important environmental risk factor for myopia.<sup>13,38,39</sup>

We found a higher risk of refractive error among native compared to migrant children, as has been reported previously.<sup>40</sup> We hypothesized that this is due to lower socioeconomic status among migrant children, which also has been widely reported.<sup>41</sup> The association between socioeconomic status and myopia prevalence is well known.<sup>18,42</sup>

Age-specific percentage of visual acuity  $\leq 20/50$  (20/40) was relatively high in 3- to 6-year-olds, which is in accordance with the development of visual acuity in young children, as also reported in previous studies.<sup>43,44</sup> Generally, 3- to 5-year-old children in the present study did not have a markedly high rate of myopia. The myopia prevalence in the present study was significantly lower than for Chinese in STARS,<sup>26</sup> and Hispanics and African-Americans in MEPEDS.<sup>25,45</sup> They were, however, similar to whites in BPEDS,<sup>46</sup> perhaps because cycloplegia is easier in children without dark irides, and slightly higher than those reported by Lan et al.,<sup>23</sup> who used more rigorous cycloplegia.

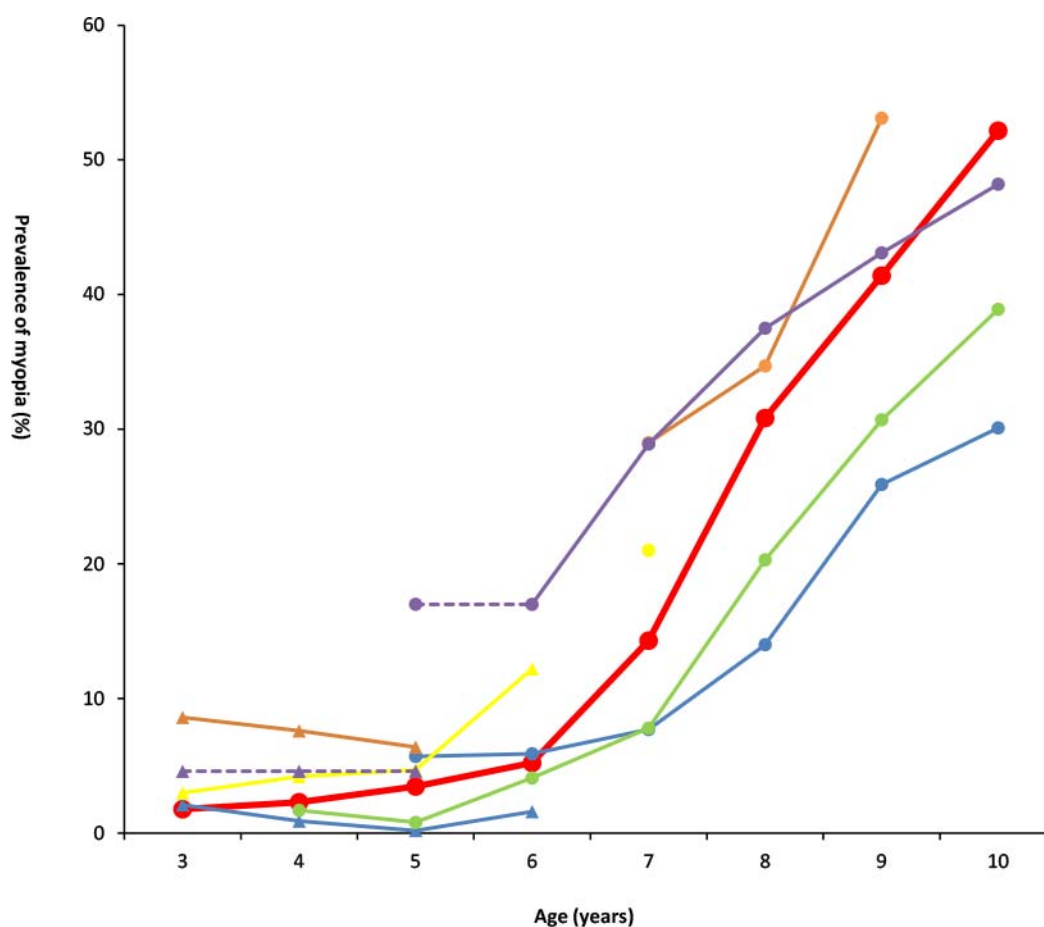
However, starting from the age of 6 years, myopia prevalence increased dramatically from 5.22% to 52.17% in 10-year-old children (an increase of approximately 10% per year). Similar patterns of rapidly-increasing myopia prevalence in primary school children also have been observed in Guangzhou, Shandong, Hong Kong, Singapore, and Taiwan, where myopia also has reached epidemic proportions (Fig. 2).<sup>6,23,26,34,37,47-50</sup> Among these studies, only the Shandong Children Eye Study (SCES) investigated children from 4 years old; however, with only 115 children in this age interval.<sup>6</sup> Besides, few studies have simultaneously documented myopia prevalence among younger, preschool-aged children. This has left it unclear whether high myopia prevalence among school-going children simply reflects already high rates among preschoolers, consistent with a greater role of genetics, or an increase of previously-low rates among preschool children,

TABLE 4. Prevalence (With 95% CIs) of Refractive Errors Among Chinese Children in Shanghai\*

| Variable | Number (%)   | Myopia Definition #1, $\leq -0.50$ D | Myopia Definition #2, $\leq -0.75$ D | Myopia Definition #3, $\leq -1.0$ D | High Myopia, $\leq -6.0$ D | Emmetropia, $-0.5 \sim -2.0$ D | Mild Hyperopia, $0.5 \sim 2.0$ D | Hyperopia, $\geq 2.0$ D | Astigmatism, $\leq -1.0$ D | Anisometropia, $\geq 1.0$ D |
|----------|--------------|--------------------------------------|--------------------------------------|-------------------------------------|----------------------------|--------------------------------|----------------------------------|-------------------------|----------------------------|-----------------------------|
| Age, y   |              |                                      |                                      |                                     |                            |                                |                                  |                         |                            |                             |
| 3        | 281 (5.1)    | 5 (1.8)<br>1.1–2.4                   | 3 (1.1)<br>0.2–1.9                   | 2 (0.7)<br>0.1–2.6†                 | 0 (0)                      | 226 (80.4)<br>76.9–84.0        | 210 (74.7)<br>71.3–78.2          | 50 (17.8)<br>14.3–21.3  | 65 (23.1)<br>17.8–28.4     | 10 (3.6)<br>2.3–4.8         |
| 4        | 650 (11.7)   | 15 (2.3)<br>1.2–3.4                  | 6 (0.9)<br>0.5–1.3                   | 3 (0.5)<br>0.1–1.3†                 | 0 (0)                      | 502 (77.2)<br>74.4–80.1        | 468 (72.0)<br>69.4–74.6          | 133 (20.5)<br>18.2–22.7 | 156 (24.0)<br>20.1–27.9    | 16 (2.5)<br>1.4–3.5         |
| 5        | 691 (12.5)   | 24 (3.5)<br>2.4–4.5                  | 13 (1.9)<br>1.0–2.7                  | 11 (1.6)<br>0.9–2.3                 | 1 (0.1)<br>0.0–0.8†        | 521 (75.4)<br>72.4–78.4        | 495 (71.6)<br>68.4–74.9          | 146 (21.1)<br>18.3–23.9 | 161 (23.3)<br>19.0–27.6    | 21 (3.0)<br>1.8–4.3         |
| 6        | 862 (15.6)   | 45 (5.2)<br>2.7–7.7                  | 33 (3.8)<br>1.7–5.9                  | 20 (2.3)<br>1.2–3.5                 | 0 (0)                      | 698 (81.0)<br>78.5–83.5        | 634 (73.5)<br>69.9–77.2          | 119 (13.8)<br>11.5–16.1 | 186 (21.6)<br>20.0–23.2    | 21 (2.4)<br>1.3–3.6         |
| 7        | 853 (15.4)   | 122 (14.3)<br>11.7–16.9              | 97 (11.4)<br>8.3–14.5                | 84 (9.9)<br>7.4–12.4                | 0 (0)                      | 649 (76.1)<br>71.5–80.7        | 539 (63.2)<br>56.7–69.7          | 82 (9.6)<br>7.1–12.1    | 179 (21.0)<br>17.5–24.5    | 28 (3.3)<br>2.7–3.9         |
| 8        | 759 (13.7)   | 234 (30.8)<br>27.8–33.9              | 199 (26.2)<br>24.1–28.3              | 166 (21.9)<br>19.9–23.9             | 3 (0.4)<br>0.1–1.2†        | 470 (61.9)<br>58.2–65.7        | 380 (50.1)<br>47.1–53.0          | 55 (7.3)<br>6.0–8.5     | 189 (24.9)<br>21.3–28.5    | 54 (7.1)<br>4.9–9.3         |
| 9        | 744 (13.4)   | 308 (41.4)<br>36.3–46.6              | 278 (37.4)<br>31.8–42.9              | 244 (32.8)<br>29.1–36.5             | 6 (0.8)<br>0.3–1.8†        | 406 (54.6)<br>48.9–60.3        | 309 (41.5)<br>36.8–46.3          | 30 (4.0)<br>2.9–5.1     | 169 (22.7)<br>17.6–27.9    | 55 (7.4)<br>5.8–9.0         |
| 10       | 692 (12.5)   | 361 (52.2)<br>46.0–58.3              | 319 (46.1)<br>39.1–53.1              | 289 (41.8)<br>36.2–47.3             | 7 (1.0)<br>0.4–1.1†        | 313 (45.2)<br>38.7–51.8        | 193 (27.9)<br>22.2–33.6          | 18 (2.6)<br>2.1–3.1     | 167 (24.1)<br>21.1–27.2    | 64 (9.3)<br>7.6–10.9        |
| Sex      |              |                                      |                                      |                                     |                            |                                |                                  |                         |                            |                             |
| Male     | 3024 (54.7)  | 607 (20.1)<br>16.1–24.0              | 525 (17.4)<br>13.5–21.2              | 451 (14.9)<br>12.0–17.9             | 10 (0.3)<br>0.2–0.4        | 2130 (70.4)<br>67.0–73.9       | 1801 (59.6)<br>55.1–64.1         | 287 (9.5)<br>8.1–10.9   | 694 (23.0)<br>20.6–25.3    | 132 (4.4)<br>3.7–5.1        |
| Female   | 2508 (45.3)  | 507 (20.2)<br>17.7–22.7              | 423 (16.9)<br>14.0–19.7              | 368 (14.7)<br>12.4–17.0             | 7 (0.3)<br>0.1–0.4         | 1655 (66.0)<br>63.5–68.5       | 1427 (56.9)<br>53.5–60.3         | 346 (13.8)<br>12.2–15.4 | 578 (23.1)<br>21.0–25.1    | 137 (5.5)<br>4.5–6.5        |
| Native   |              |                                      |                                      |                                     |                            |                                |                                  |                         |                            |                             |
| Native   | 2843         | 612 (21.5)<br>16.8–26.3              | 525 (18.5)<br>13.6–23.4              | 458 (16.1)<br>12.3–19.9             | 13 (0.5)<br>0.3–0.6        | 1909 (67.1)<br>63.3–70.9       | 1638 (57.6)<br>53.2–62.0         | 322 (11.3)<br>8.9–13.8  | 726 (25.5)<br>23.2–27.9    | 140 (4.9)<br>3.9–6          |
| Migrant  | 2689         | 502 (18.7)<br>13.9–23.4              | 423 (15.7)<br>11–20.5                | 361 (13.4)<br>9.7–17.2              | 4 (0.2)<br>0–0.3           | 1876 (69.8)<br>66.2–73.3       | 1590 (59.1)<br>55–63.2           | 311 (11.6)<br>9.6–13.5  | 546 (20.3)<br>18–22.6      | 129 (4.8)<br>3.9–5.7        |
| Total    | 5532 (100.0) | 1114 (20.1)<br>16.9–23.4             | 948 (17.1)<br>13.7–20.5              | 819 (14.8)<br>12.2–17.4             | 17 (0.3)<br>0.2–0.4        | 3785 (68.4)<br>65.6–71.2       | 3228 (58.4)<br>54.3–62.4         | 633 (11.4)<br>10.5–12.4 | 1272 (23.0)<br>21.3–24.7   | 269 (4.9)<br>4.2–5.6        |

\* Only children undergoing cycloplegic autorefractometry were included in these analyses.

† Exact binomial distribution without considering the cluster design effect was used to calculate 95% CIs.



**FIGURE 2.** Age-specific myopia prevalence (cycloplegic SE  $\leq -0.5$  D) in areas of Asia severely affected by myopia.<sup>6,24,27,34,37,42–45</sup> Red line stands for the prevalence in Shanghai; blue line stands for the prevalence in Guangzhou; green line stands for the prevalence in Shandong; orange line stands for the prevalence in Singapore; yellow line stands for the prevalence in Taiwan; purple line stands for the prevalence in Hongkong. The lines with full circle stand for the prevalence for school-aged children; and the lines with full triangle stand for the prevalence for preschool children. Dashed lines stand for the average prevalence between the age intervals.

indicative of an environmental role from school exposure. The current study is among the first to elucidate this due to the inclusion of preschool and primary school cohorts, and it appears that the latter situation is the case.

Female sex has been reported to be associated with higher myopia risk.<sup>6,33,35,51</sup> Our failure to detect this association in our overall cohort could be due to changes over time: girls were less myopic before age 8, and became as or more myopic than boys subsequently (Fig. 1). As children grow older, differences in myopia prevalence between girls and boys may become obvious.<sup>6,35,51</sup>

In the present population, uncorrected refractive error was the major cause of VI, responsible for >90% of impairment. Although VI caused by refractive error can be corrected safely and inexpensively by a pair of glasses,<sup>52</sup> fewer than one in three children needing glasses in this population had them. Among those with UCVA  $\leq 20/40$  in the better-seeing eye, only 28.7% were wearing glasses in Jiading, similar to the figure reported in Beijing Shunyi (29.3%),<sup>51</sup> but lower than in Guangzhou (65.9%)<sup>34</sup> and in Guangdong Yangxi (46.5%).<sup>53</sup> It is likely that a proportion of children who did not wear glasses on the day of examination could have left their glasses at home, and those children were not included in the calculation of glasses coverage. A likely reason for the low glasses coverage in this young cohort of children might be the widely-accepted idea among Chinese parents that wearing glasses harms the

vision and causes more rapid progression of myopia, particularly among younger children. (Our cohort was younger than those in Guangzhou and Yangxi: mean age of 6.79 vs. 10.47 and 14.78, respectively). This is despite the fact that the belief that glasses wear worsens children's UCVA has recently been demonstrated to be false in a randomized controlled trial.<sup>52</sup>

The strength of study lies in the randomized sampling strategy, large sample size, and high rates of participation, the assessment of refractive error using cycloplegia in the majority of children, and the careful quality control throughout implementation of the study. Importantly, preschool (3–5 years) and school-aged (6–10 years) children were included in the study, allowing the impact of school attendance on prevalence to be elucidated more clearly than in previous population studies in China.

Limitations of the study also must be acknowledged. Parental consent for cycloplegia could be obtained only for two-thirds of children. The rate for successful visual acuity test and cycloplegic refraction was particularly low for children 3 years old, due to a combination of parental concern over side effects and poor cooperation in this age group. Differences between children with and without cycloplegia generally were modest, and would not have been expected to have a large impact. Second, only one district, Jiading, was included in the study. Therefore, the prevalence of refractive errors in the present study could not be representative of the whole of



Shanghai. The higher proportion of high level schools in the present study could probably overestimate the prevalence of myopia in Shanghai; however, it is helpful to better understand their impact on myopia. Third, the present study was cross-sectional. Therefore, attribution of a causal relationship between educational exposure and myopia risk must be made with caution. It has been reported that observational studies may underestimate the true impact of education on myopia.<sup>54</sup> The Elaborative Shanghai Childhood Ocular Refractive Development Study (E-SCORDS) will follow this cohort of children for 4 years, which may help to further elucidate the relationship between educational exposure and myopia. Finally, we did not include some important risk factors for myopia, such as parental myopia.<sup>55,56</sup> The relationship between these additional factors and myopia also will be discussed in our future study using longitudinal data.

Despite its limitations, this study is among the first population-based reports in China to include preschool and school-aged cohorts of children. Our findings add further weight to the idea that educational exposure is an important risk factor for children's myopia in China. Strategies to reduce the educational pressure experienced by Chinese children are needed to reduce the burden of myopia and myopia-related diseases, such as retinal detachment, glaucoma, and cataract.

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